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GEOSTATISTICAL STUDY ON EL-HARRA IRON ORE DEPOSIT

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فــى هــذا البحث تم استخدام الطرق الجيوإحصائية لدراسة سلوك عنصر الحديد فى جسم خام الحديد بمنطقة الحارة بالواحات البحـــرية بالصحراء الغربية بمصر. وتمت الدراسة مع الأخذ فى الاعتبار الوضع الجيولوجى للخام الذى أدى إلى تقسيم جسم الخـــام إلــــى نطاقين نتيجة تأثره بفالق. ولكل نطاق تم إنشاء دوال التباين الاتجاهية وكذلك النطاقية حتى يمكن مقارنتها بدوال التباين الاتجاهية والنطاقية لجسم الخام كوحدة واحدة ودون اعتبار الخواص الجيولوجية له.

ABSTRACT

The iron ore deposits of El Bahariya depression are found in four localities of the northeastern plateau of the Bahariya Depression, Western Desert of Egypt. These localities are El-Gidida, Ghorabi, El-Harra and Nasser. Geostatistical technique has been used through the present work to study the behaviour of the iron content of El-Harra iron ore deposits of El Bahariya depression, by taking Geological characteristics into account.

The orebody of this occurrence is divided into two zones, for each zone and then for the whole deposit, variograms have been constructed to show the effect of the geological setting of the ore on the iron content variability within the deposit. To examine the presence of directional anisotropy of the orebody, directional variograms have been constructed. Then, global variogram has been constructed for each zone and for the whole area to show zonal anisotropy within the orebody. Both directional and zonal anisotropy as reflected by the variogram parameters illustrate the effect of faults and ore types on the orebody and hence the effect of taking the geological characteristics into account when applying geostatistical analysis for El-Harra iron ore evaluation.

1. INTRODUCTION

Geostatistical techniques could be applied to evaluate any ore deposit without considering its geological features, but the result in such a case will not give reliable estimate. To minimize the evaluation error, constructing variogram which is the base of any geostatistical study should built on the geological setting of the studied ore deposit. Construction of variograms plays an important role in studying the behavior of the ore, for example, the continuity and nature of mineralization within the orebody and hence its variation in grade over the deposit by considering the positions of the available samples within any deposit [1]. When constructing variograms, the samples must belong to one mineralized zone to represent its specific spatial variability [2]. These zones could be defined by studying the geology of the ore body including its structural, mineralogical, and chemical properties.

Based on previous geological studies, which were carried out on the El Harra iron ore deposit, it is clear that the ore body could be divided structurally and stratigraphically into two zones [3]. This division might affect the mineralogical characteristics of the orebody and the ultimate ore reserve calculation. However, this could be investigated through geostatistical modeling of the orebody by considering its geology, and hence variograms have been constructed for individual zones.

For sake of comparison, it is assumed that the structural geology has no effect on the mineralization of the orebody, and the whole deposit is considered as one zone for which variograms could be constructed.

Before starting the geostatistical analysis, conventional statistical analysis has been performed to throw the light on the distribution of iron content and its parameters; mean, standard deviation and coefficient of variation within the different zones.

The present study is based on sampling information derived from (200 x 200) m drill-hole grid system comprising 94 drill-hole, as shown in Fig. 1. For each zone, a database has been established using only the drill-hole data which fall within each zone. Later, all the databases were merged into one to represent the whole area. For each drill-hole, northing, easting, elevation and iron content were provided in the database.

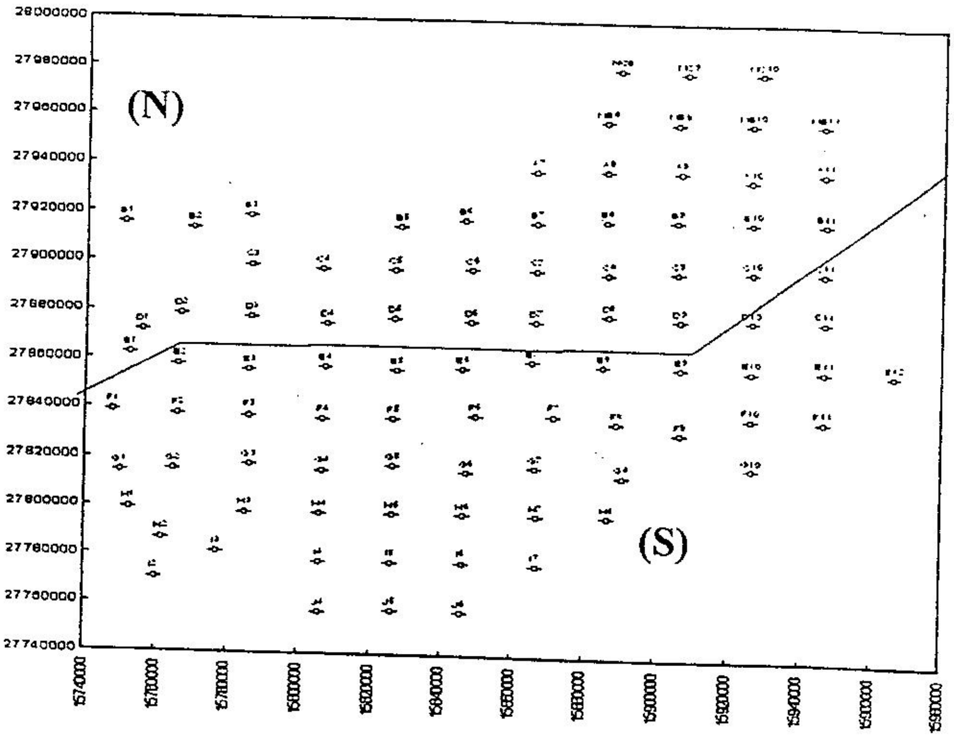


Fig. 1 Bore holes location and zones of El-Harra area.

2. GEOLOGIC SETTING, ORE TYPES AND GENESIS

The ironstone succession of El Harra mine ores (Lutetian) is bounded and internally punctuated by unconformities with superimposed karst and pedogenetic features (Fig. 2). In Naqb El Harra scrap, the lutetian ironstone succession is well developed and best preserved. It oversteps the Cenomanian Bahariya clastics and is erosively truncated by the Upper Eocene glauconitic ironstone and glaucony facies of the Hamra Formation (Bartonian–priaborian).

The original ironstone succession is differentiated into two main stratigraphic units, being from base to top [4]:

1.Variegated mud-ironstone (0.2-1.5m):

This unit is well developed along the Cenomanian-Lutetian unconformity surface. It varies in thickness from few centimeters up to 1.5m. Such variation is almost related to the paleorelief of the

Cretaceous-Eocene unconformity surface and the erosive nature of the overlying nummulitic ironstone beds [3].

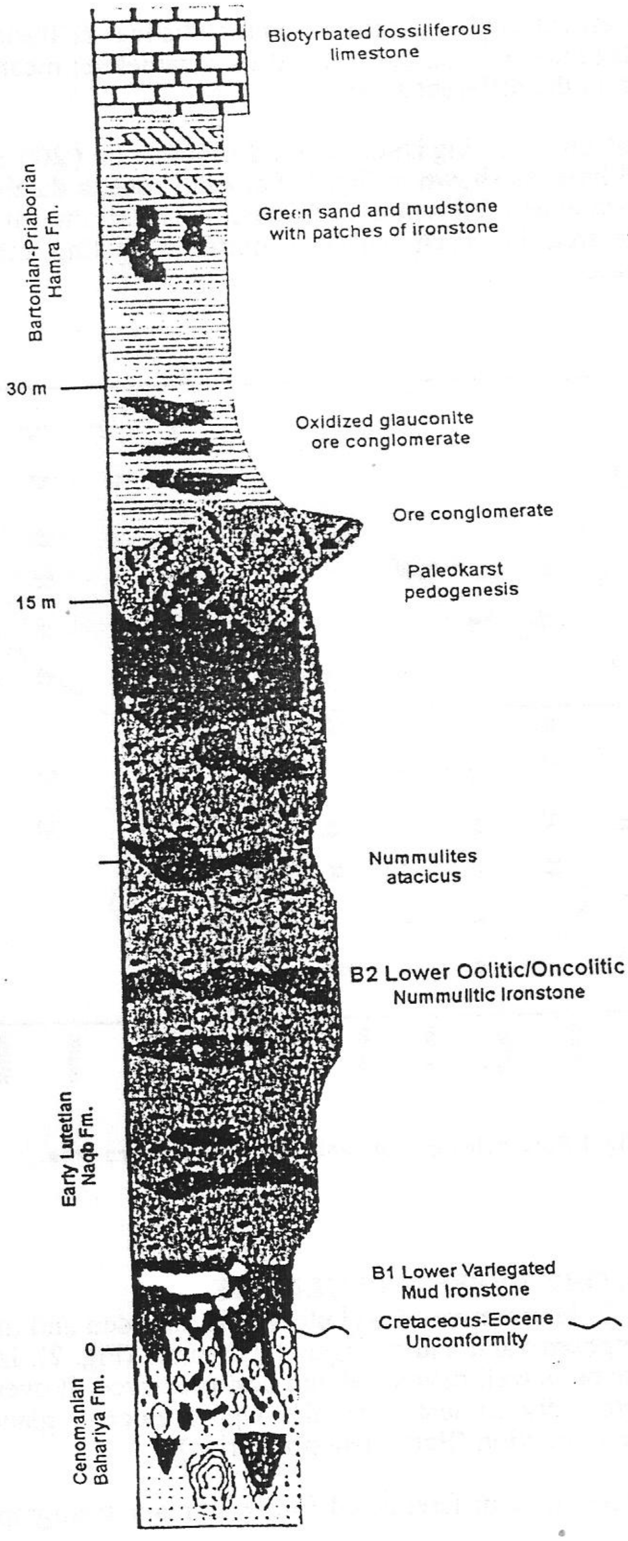


Fig. 2. Fine lithostratigraphy of the Lutetian ironstone at the upstream of wadi El Harra, El Harra mine area. (after Helba et al., 2001).

2. OOLITIC/ONCOLITIC AND NUMMULITIC IRONSTONE (1.5-6M):

It is the most pervasive and thickest ironstone unit. Its greatest thickness (about 6m) is measured at El Harra section (Fig. 2). The unit consists mainly of medium to thick nummulitic ironstone beds (10-30cm thickness, for each) which swell and pinch laterally. Discontinuous thin layers and laminae of ochreous mud-ironstone commonly exist along the irregular contacts of the main nummulitic/oolitic ironstone beds.Kaolinitic and alunitic nodules, being in places coalesced to form enterolithic-like lenses, are common. A cockade structure consisting of rotten rubbles that are coated by colloform iron oxide crusts is also recorded. Above the paleokarst surface and the related soil products rest unconformably ore conglomerates, being composed of ironstone boulders and gravels setting in ochreous soily matrix.

2. 1. Structural Model

El Harra area is characterized by a certain structure irrepeatable in the other areas. The Cenomanian rocks are highly deformed by folding and tilting while the Eocene beds show no rotation except near the major faults. This indicates multiphases of deformation affecting such area [4,5].

El Harra area represents elliptical dome with NE-SW axial trace. The crest of the dome is occupied by flat-laying Middle Eocene rocks. The area suffered from two master faults trending NE-SW with right-lateral sense of movement as shown in Fig. 3. These faults mildly affect the Eocene beds with insignificant bed rotation or folding. The two faults make extended graben form in the NE-SW direction. The main importance of such graben came from the preservation of El Harra iron ore in its trough where the equivalent section is tripped-out from the shoulders of the graben. Also, this graben traps El Hamra Formation, which is missed in the neighboring areas. The recent playa lakes are also occupying the low land area of this graben.

Fig. 3. Interpreted aerial photo of El Harra area. (after Khalil, M., M., 1995).

3. STATISTICAL ANALYSIS

Study of the geology of the El Harra, including faulting, folding, and stratigraphy of the orebody, revealed that it could be divided into two different zones; the northern (N), and southern (S) ores as shown in Fig 1.

Statistical analysis, in the present study, gives the distribution of iron content and the standard parameters; mean, standard deviation, and coefficient of variation. The histograms in Fig. 4 illustrate that the iron content does not have the same distribution within the two zones and for the whole deposit.

Also, it is obvious from Table 1 that a little difference is found in the average iron content (ranges from 38.42% to 41.88%), whereas a clear difference is found in the coefficient of variation (ranges from 14% to 24%) of the two zones and the whole deposit of El-Harra area.

Table 1. Statistical Parameters.

Zone	Mean	S.D.	Coef. Of Var.
N	38.42	9.28	0.24
S	41.88	5.81	0.14
Total area	40.34	7.71	0.19

Although there is difference in the coefficient of variation values, which represents the variability of the orebody from statistical points of view, but they are considered at low rates. This result might give an indication that the ore variability and hence mineralization characteristics of the ore body should be checked geostatistically to show this behavior.

Traditional statistical methods are based on the assumption that all sample values are equally representative of the deposit under study, and the physical positions of the samples with respect to each other are not taken into account [6]. This is the reason of insufficient information about characteristics of the orebody yield by statistical analysis.

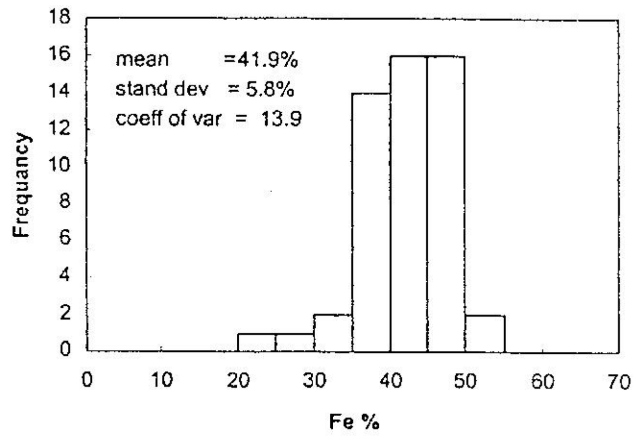
4. CONSTRUCTING OF VARIOGRAMS

Computing an experimental variogram from a set of randomly spaced data involves finding pairs of data that are oriented in the required direction, determining the distance between the samples, then summing the squared differences of the grades and dividing by the number of pairs [7].

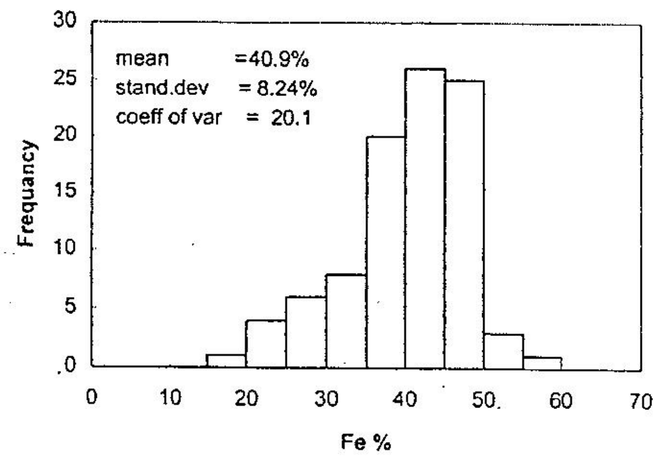
Construction of variogram reflects the variability of the ore mineralization and could be used to differentiate between characteristics of the different zones of an orebody and as a base of the next steps in the geostatistical evaluation, such as kriging. To illustrate the effect of geology of the ore body, directional variograms have been constructed for each zone and for the whole area to check the directional anisotropy characteristics for each case and for the whole area [8].

4.1 Directional Anisotropy

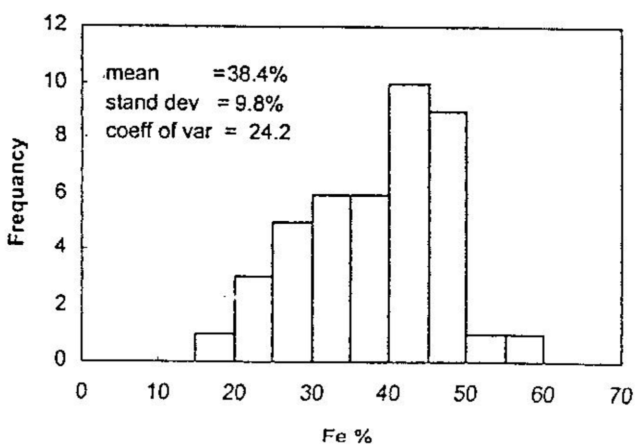
The constructed directional variograms for the whole deposit tend to be close to each other. But the variograms follow linear model with nugget effect through N-S direction while spherical model through directions E-W, NE-SW, and NW-SE with a little difference in their parameters as shown in Fig. 5 and Table 2. This indicatesthat low different mineralization characteristics through the different directions within El-Harra whole deposit are recorded and therefore the orebody, in this case, is probable to be considered anisotropic even when neglecting the effect of its geology.



South El Harra (S).



El Harra area (T).



North El Harra (N).

Fig. 4. Histograms of iron content for the whole area and for different zone.

Table 2. Directional Variogram Parameters.

Zone		N-S	E-W	NE-SW	NW-SE
Harra-T	Co (%)2	27.2	2.7	5	2.6
	C (%)2	-	53.8	48	53
	a (m)	-	400	350	380
N	Co (%)2	12.5	14.8	10.1	23.5
	C (%)2	62	81	77	-
	a (m)	400	350	420	-
S	Co (%)2	6.8	10	3.1	4.2
	C (%)2	-	31	30.5	35
	a (m)	-	320	300	380

However, when considering the effect of the geology of the ore body, i.e., considering both of faulting and stratigraphy of the orebody, directional variograms for the two zones reflect the clear presence of anisotropy in some zones, particularly in the north zone (N).

Figures 6 and 7 show that the variograms in the NE-SW direction in most of zones reflect higher continuity than the other directions, i.e, anisotropy is definitely indicated. The variogram parameters, as deduced from the fitted models support this result. They vary from one direction to another within wide ranges than those for the whole area. This indicates that some of the mineralization characteristics do not have the chance to appear in the first case. Treating the ore body as one zone caused the disappearance of the different mineralization behavior.

The direction (NE-SW) recorded the highest range of influence (420 m) and the lowest sill (30.5%2) and tend to have the highest level of continuity than the other directions. It is observed that the direction of higher continuity is the same as the direction of the major fault trending NE-SW. This might reflect the effect of this structure on the mineralization of the ore body and make its variability smaller. The mineral distribution in that direction could then be considered more homogeneous. If this result is taken into account during the planning and production stages, the problems resulting from variation in the ore body mineralization, such as the presence of an unexpected poor mineralized zone or intercalations, could be avoided or decreased.

4. 2. Zonal Anisotropy

The variogram behavior can vary within the different zones of the orebody indicating the presence of zonal anisotropy. To prove the presence of zonal anisotropy within El-Harra ore deposit and to support the concept of dividing the orebody into zones according to its geologic setting, global variograms (without considering directions) have been constructed for the whole deposit and for each zone as shown in Fig. 8.

Table 3. Zonal Variogram Parameters.

Zone	Range a, m	Sill C, $(\%)^2$	Nugget Effect C_o $(\%)^2$
Whole Area	400	50	15
N	350	81	31
S	400	32	5

Global variograms and their fitted models for the different cases illustrate that the variability of the orebody is not the same within them. Zone S as shown in Table 3 has high range of influence and lowest sill and nugget effect values to demonstrate the least variability and hence the best mineralization continuity. At the time, zone N gives another type of continuity where it has the highest variability and low mineralization continuity. This indicates clearly the presence of zonal anisotropy.

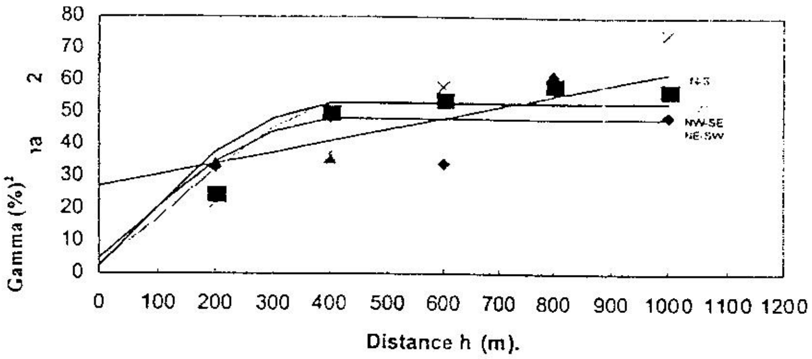


Fig. 5. Directional variogram models for the whole El Harra area (T).

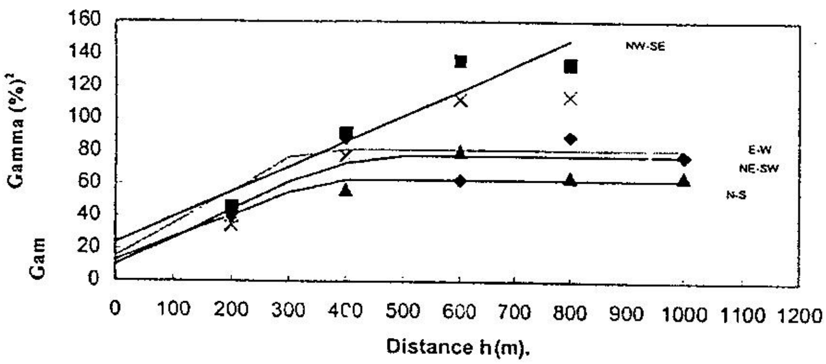


Fig. 6. Models variogram for the north zone (N).

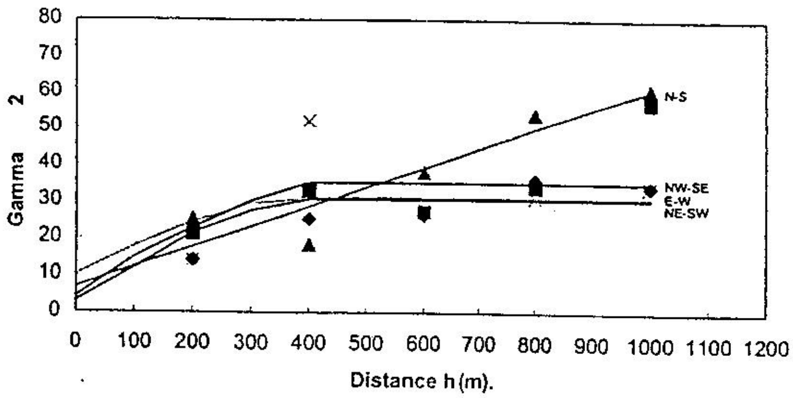


Fig. 7. Models variogram for the south zone (S).

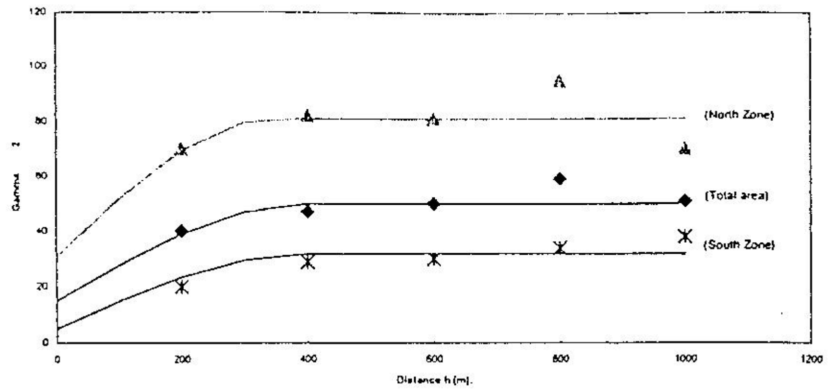


Fig. 8. Zonal variogram models.

5. CONCLUSION

A geostatistical study in the present work on El Harra iron ore deposit supported the possibility of dividing the ore deposit into two different zones according its geologic setting. Global variograms for the two zones and for the whole area demonstrated that iron ore characteristics vary clearly within the two zones and therefore the orebody should not be taken as one zone when evaluating El-Harra area.

Also directional variograms for the two zones clarify the anisotropic nature of the orebody where treating it as one zone lead to an ambiguity about its anisotropic mineralization characteristics. In addition, statistical analysis did not give enough information about the variability of iron content, though it gave good indication about that variability where different coefficient of variation values have been found for the two zones.

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